U.S. DEPARTMENT OF ENERGY

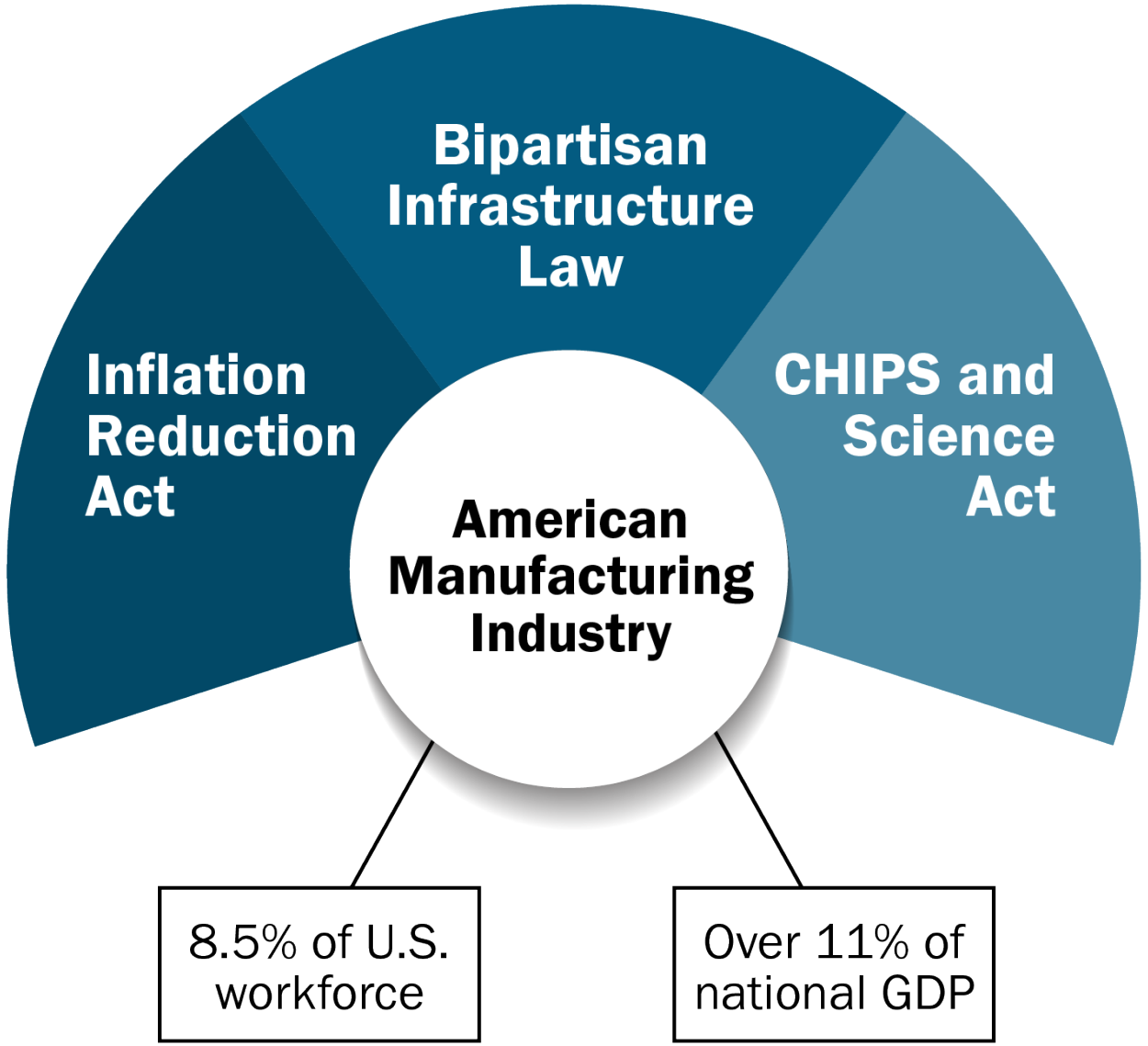
Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

ADVANCED MATERIALS & MANUFACTURING TECHNOLOGIES OFFICE

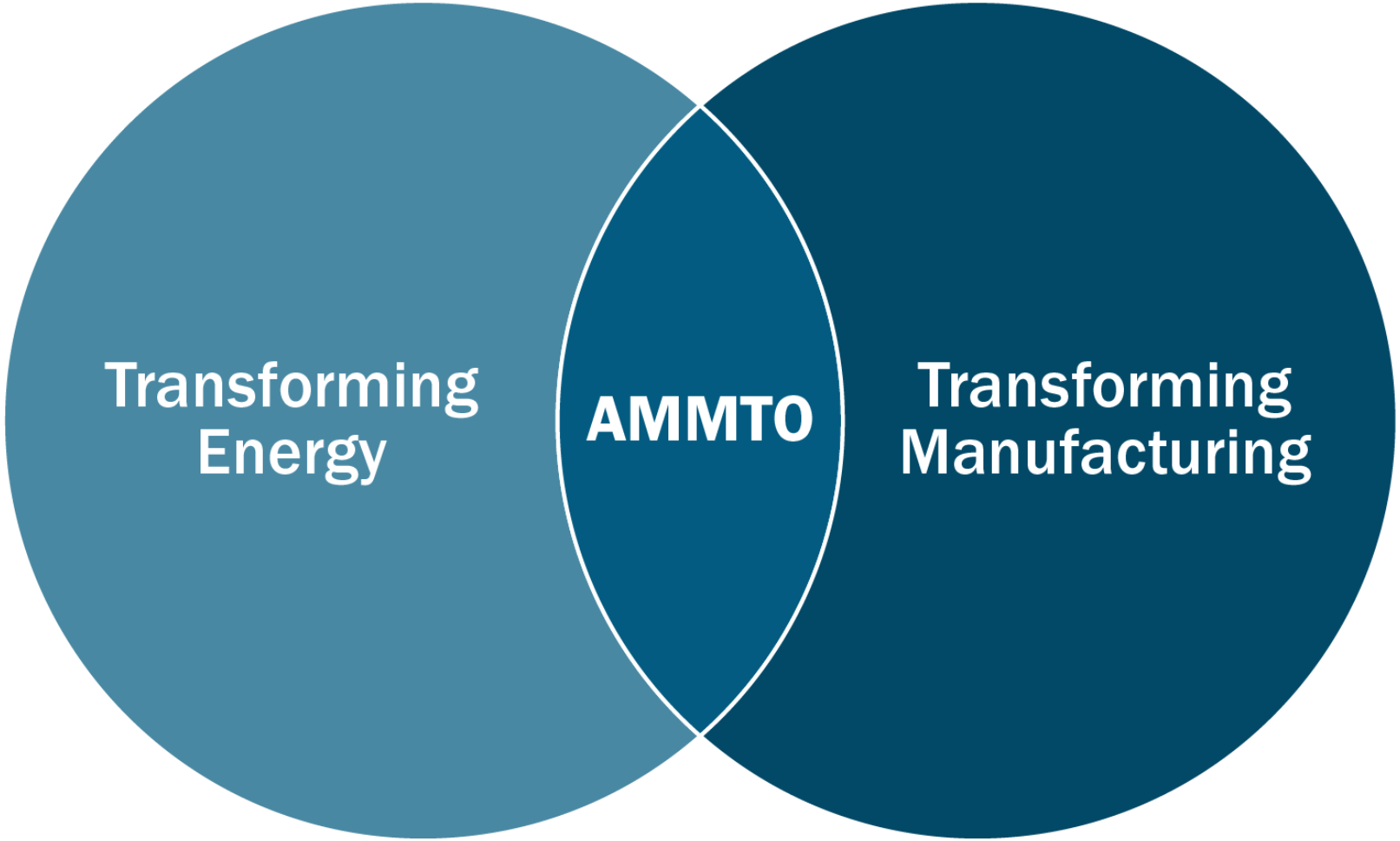
Perspectives and Progress on Critical Materials

Helena Khazdozian, PhD
Senior Technology Manager

Unprecedented Federal Investment in Manufacturing



AMMTO's Unique Role in American Manufacturing



What is AMMTO All About?

Vision

A globally competitive U.S. manufacturing sector that accelerates the adoption of innovative materials and manufacturing technologies in support of a clean, decarbonized economy.

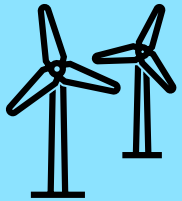
Mission

We inspire people and drive innovation to transform materials and manufacturing for America's energy future.

AMMTO's Subprogram Structure

NEXT-GENERATION MATERIALS & PROCESSES

Advanced Manufacturing Processes and Systems



High Performance Materials

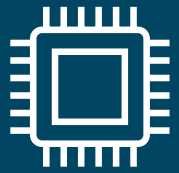
SECURE & SUSTAINABLE MATERIALS

Circular Economy Technologies and Systems

Critical Materials

ENERGY TECHNOLOGY MANUFACTURING & WORKFORCE

Energy Conversion and Storage Manufacturing



Semiconductors, Electronics, and Other Technologies Manufacturing

Entrepreneurial Ecosystems and Advanced Mfg. Workforce

Critical Minerals & Materials (CMM) RD&D in AMMTO

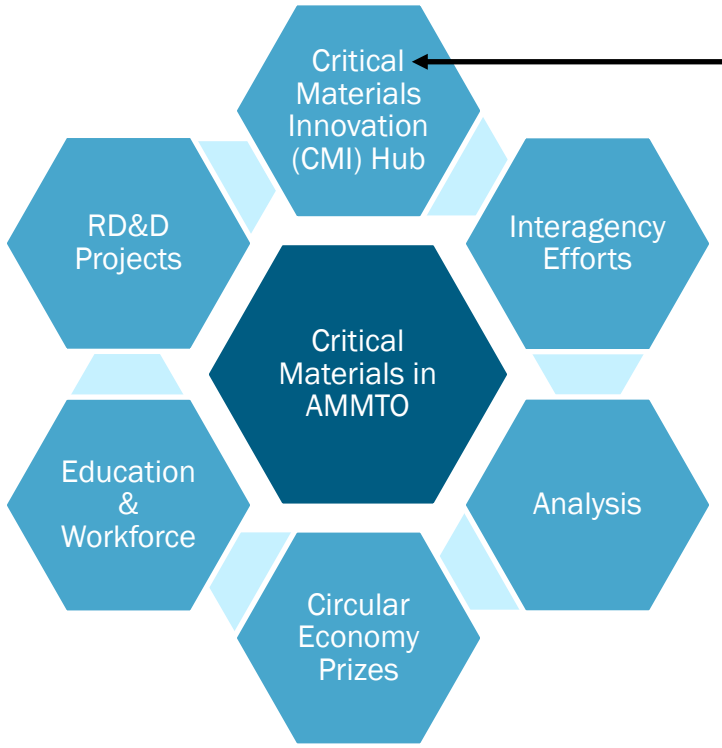
AMMTO's CMM portfolio addresses high-impact opportunities and challenges across the entire life cycle of high priority CMM for energy technologies

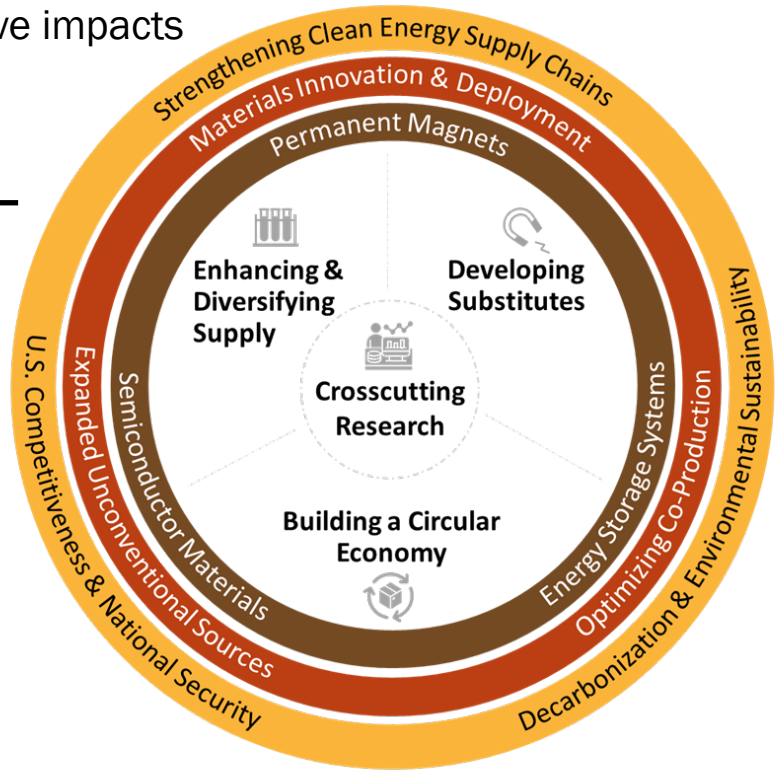
- **Research, development, and demonstration (RD&D) for high-priority critical minerals and materials, aligned with the DOE Critical Minerals and Materials Strategy, to:**
  - Build resilient domestic supply chains to support the clean energy transition
  - Accelerate adoption of innovative S&T solutions to improve efficiency and reduce negative impacts
  - Foster a robust innovation ecosystem to meet industry and research workforce needs

RD&D Projects

- R&D to advance next-generation technologies, in coordination with the CMI Hub
- Lithium RD&D Virtual Center to integrate and expand the innovation ecosystem
- Demonstrate improved industrial technologies to address supply chain gaps
- De-risk and validation of innovation through the Critical Materials Accelerator Program

Critical Materials Assessment

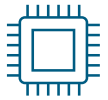
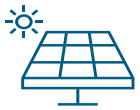




CMI | Critical Materials Innovation Hub

The “Electric Eighteen”

Critical Materials – The Building Blocks for Electrification

Neodymium, Praseodymium, Dysprosium, & Terbium		**Magnets** for wind turbine generators & EV motors
Cobalt, Lithium, Graphite, Nickel & Fluorine		**Batteries** for electric vehicles & grid storage
Iridium & Platinum		**Electrolyzers** for green hydrogen production & **fuel cells** used energy storage
Gallium & Silicon Carbide*		**Semiconductors** enable high voltage power & efficient lighting
Magnesium & Aluminum		**Lightweight alloys** in transportation
Silicon*		**Solar panels**, lightweight alloys, electrical steel
Copper* & Electrical Steel*		Wind turbine **generators** & EV **motors**

Goals

100% clean electricity by 2035; Net-zero economy by 2050

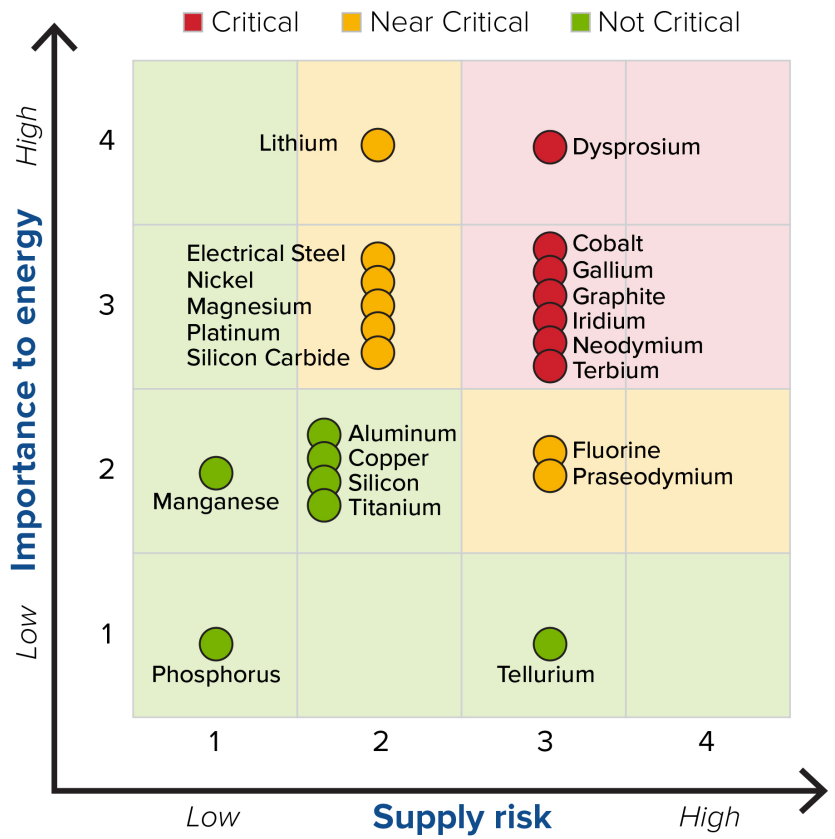
50% EV adoption by 2030; 30 GW offshore wind by 2030; Cost of Clean Hydrogen $1/kg by 2031

**Not on the U.S. Geological Survey Critical Minerals List*

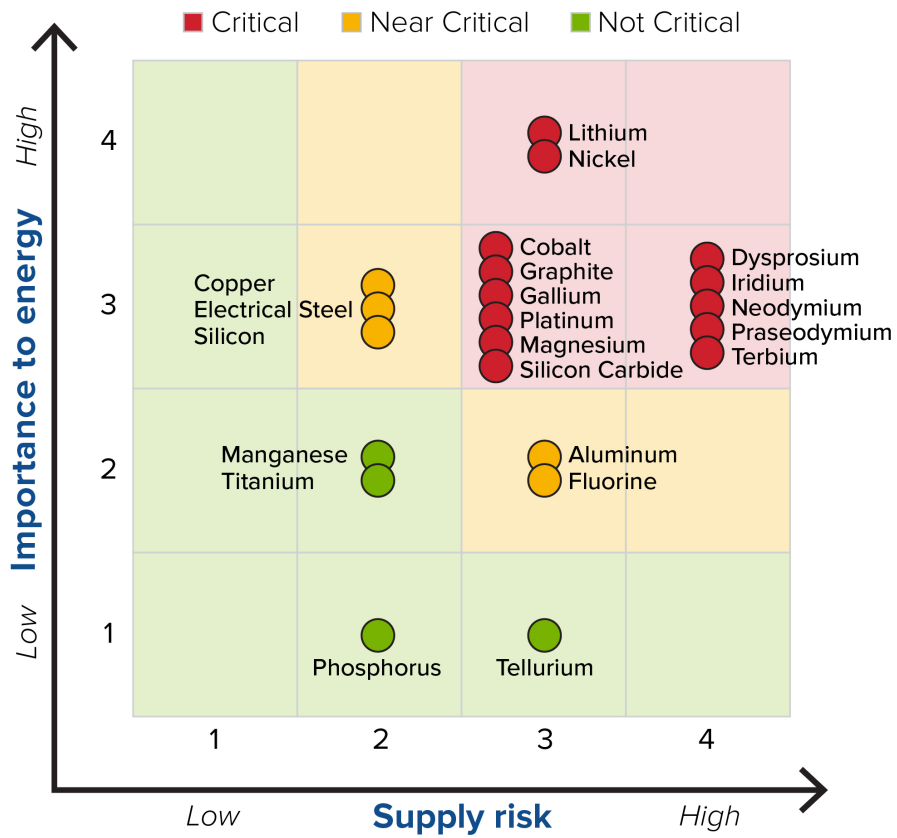
Determining Material Criticality

Critical materials are materials that have high risk for supply disruption and serve an essential function in one or more energy technologies

SHORT TERM 2020-2025



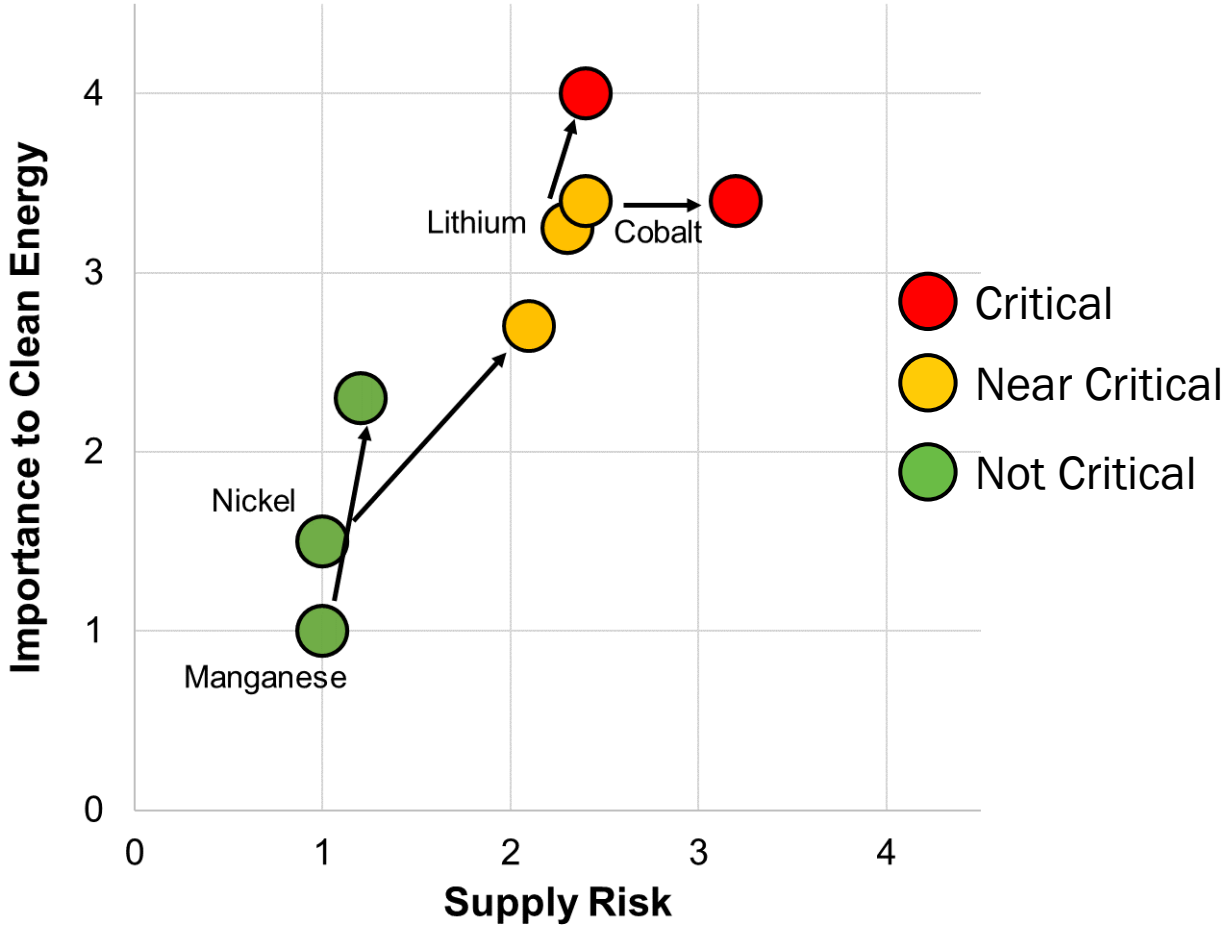
MEDIUM TERM 2025-2035



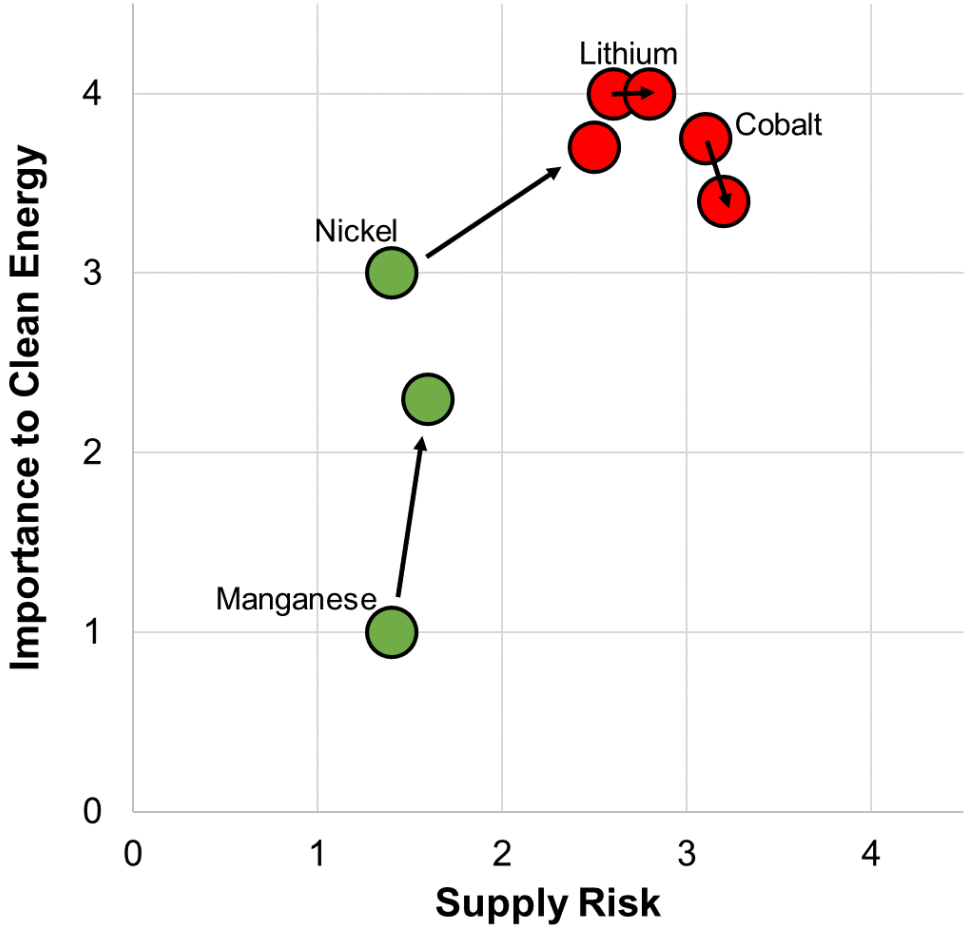
https://www.energy.gov/cmm/what-are-critical-materials-and-critical-minerals

Battery Materials: Criticality from 2019 to 2023

Short term criticality matrix

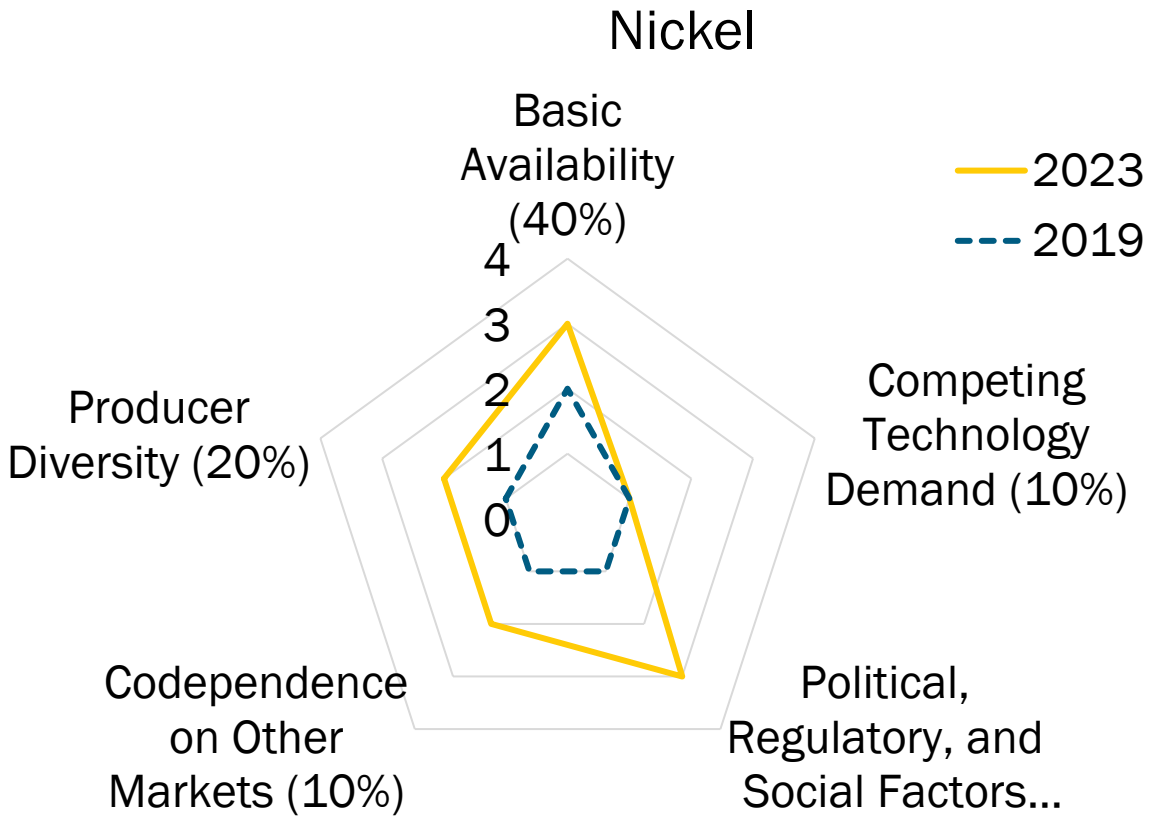


Medium term criticality matrix



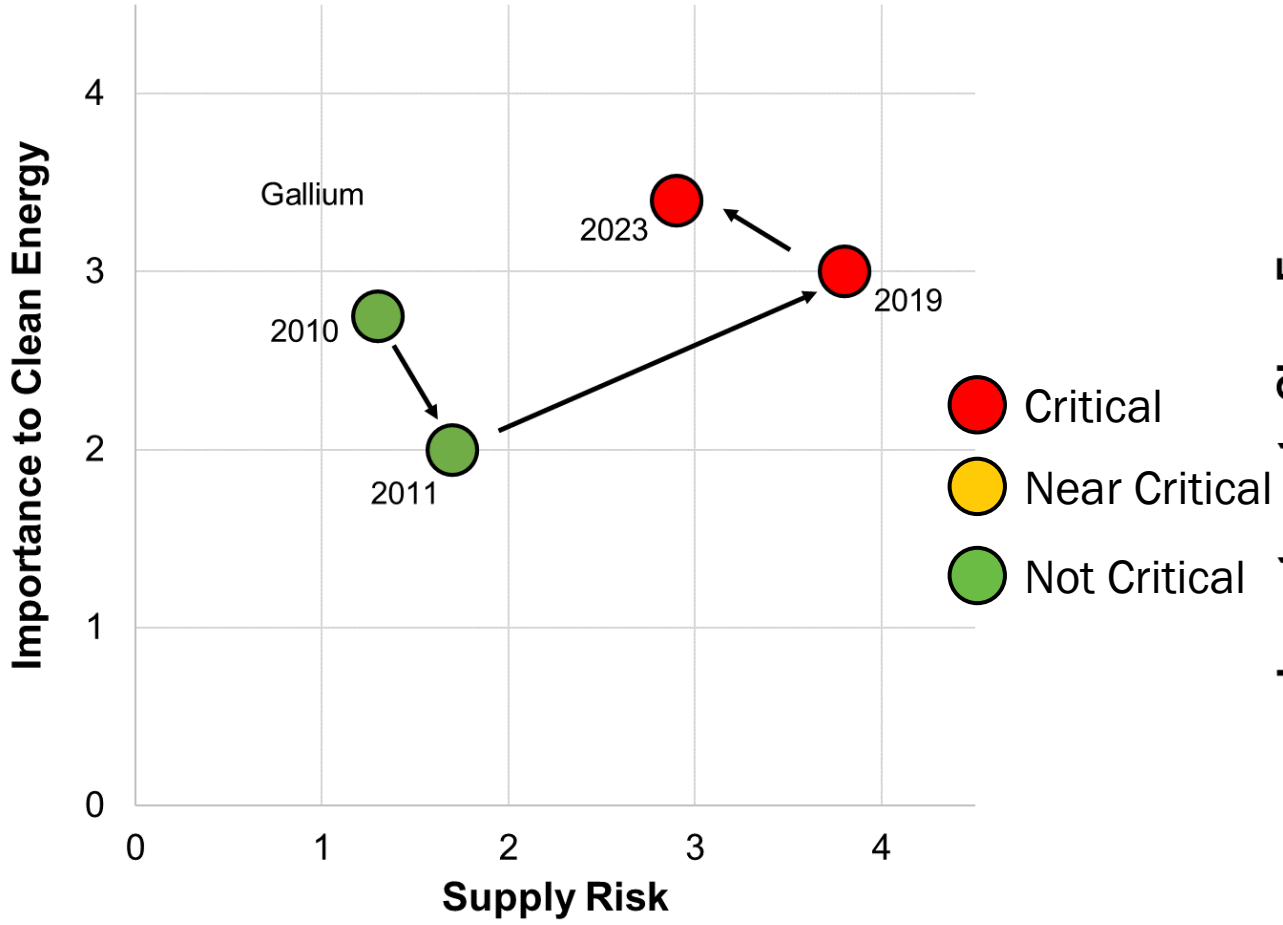
Battery Materials: Nickel

- **In the medium term, basic availability risk of nickel is underpinned by the broader availability of laterite ores compared to sulphide ores.**
  - It is more costly to produce Class 1 nickel from laterite than sulphide ores.
  - Almost half of mined nickel is produced in Indonesia.
  - There is greater producer diversity for mining that is used to produce Class I nickel; Russia is the largest producer and refiner, followed by China.

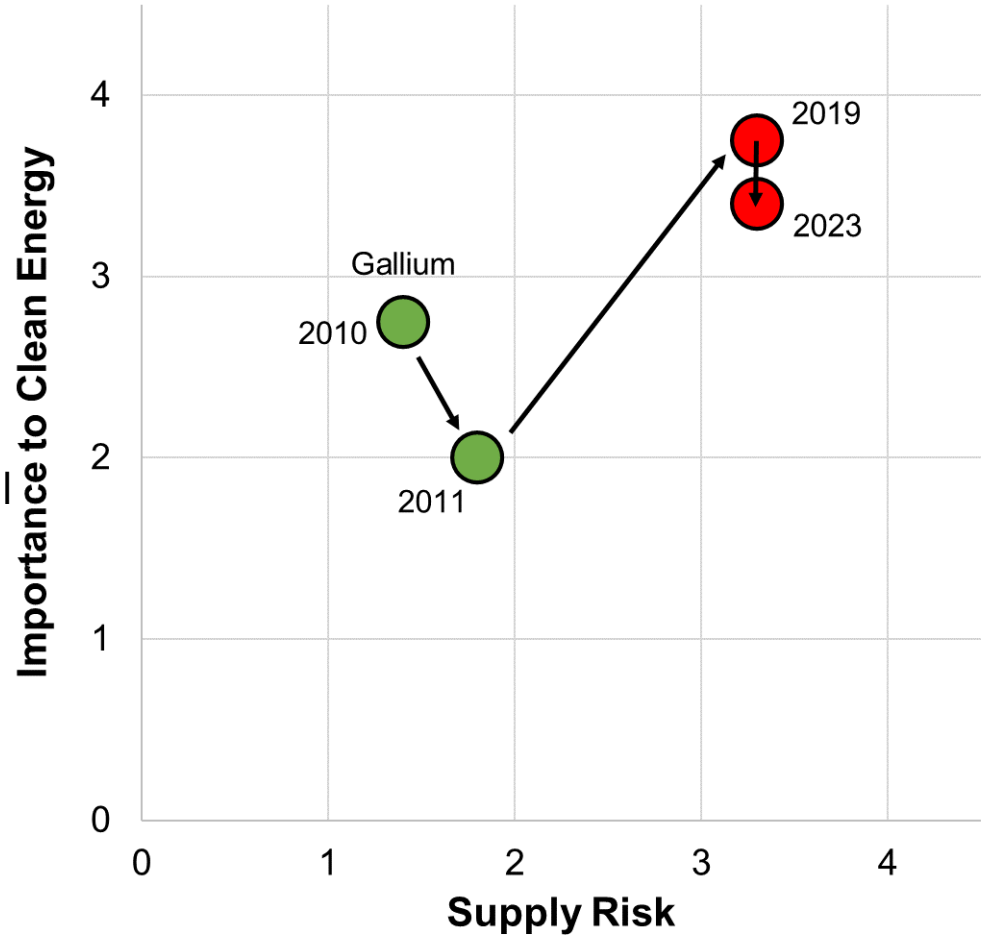


Semiconductor Materials: Gallium

Short term criticality matrix

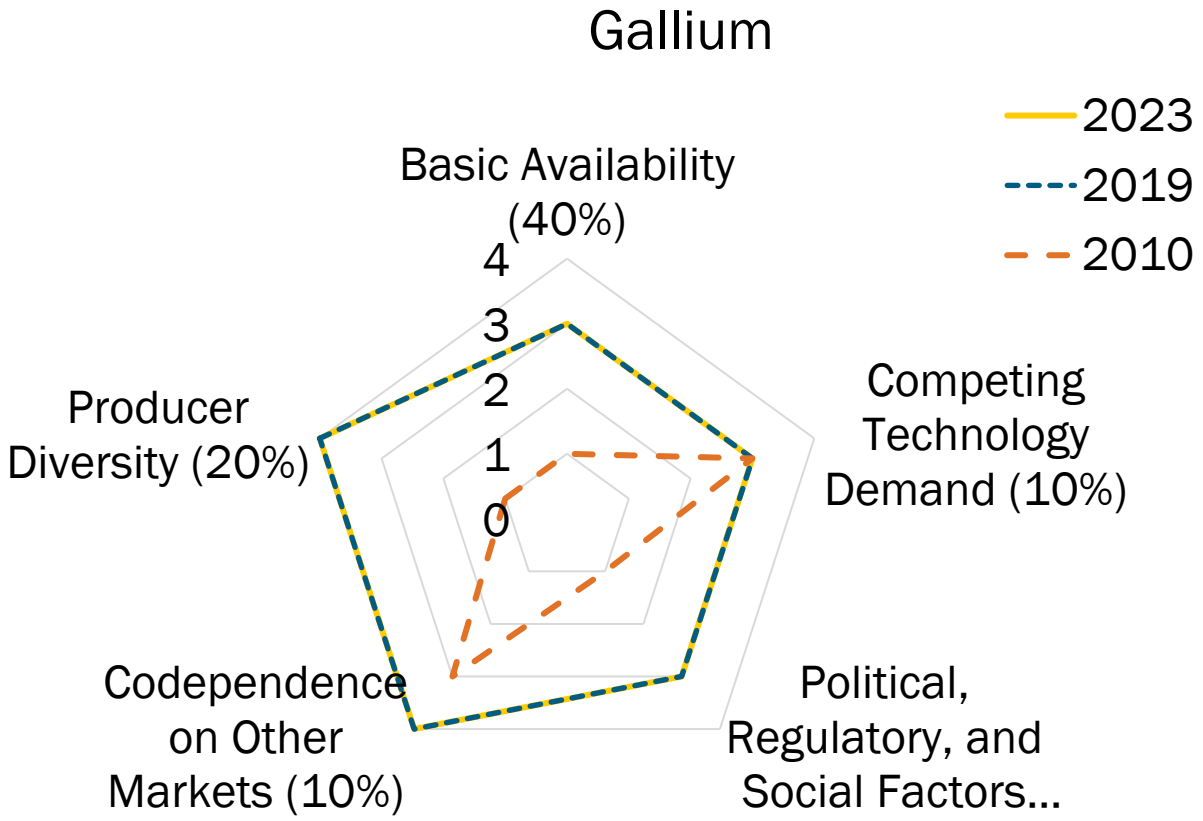


Medium term criticality matrix



Semiconductor Materials: Gallium

- **Gallium's importance to energy is driven by its use in LEDs, solar panels, power electronics, and magnets, accounting for ~77 to 87% of its market.**
  - LEDs have gained a global market share of 50%.
- **Basic availability is a concern for both the short and medium terms**
  - 97% of market share for gallium production is in China. Production is not operating at capacity.
  - 90% of gallium is produced as a byproduct of bauxite.
  - **Gallium is also produced as a byproduct of zinc residues.**



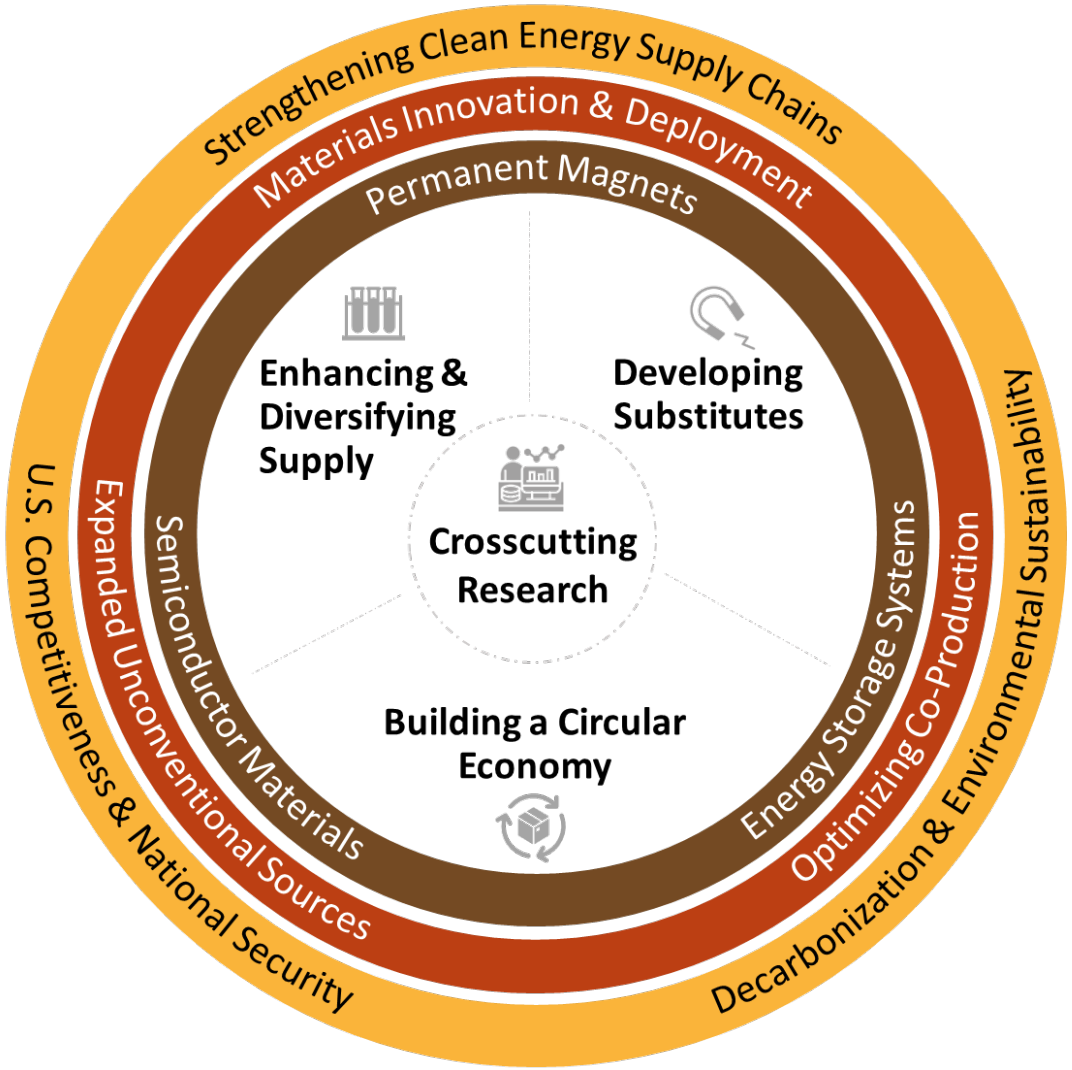
Critical Materials Innovation Hub (CMI Hub)

formerly known as the Critical Materials Institute

CMI Critical Materials Innovation Hub

Portfolio: 32 early-stage research projects

Innovative Ecosystem: Network of 9 DOE National Laboratories, 20 Universities and 30 active private sector team members



Phase III of operations, building on 10 years of success

20 Licensed Technologies	**$80M+** Follow-on Funding	
600+ Refereed Publications	**12** R&D 100 Awards	**50** Patents Awarded

CMI Hub Facilities & Capabilities

CMI Critical Materials Innovation Hub

FACILITIES

High-throughput centrifugal contactor system

Solvent extraction test bed facilities

Multi-stage solvent extraction lab scale mixer-settler demo test facility

Materials Preparation Facility

Magnet Scale-up and Prototyping Facility (MSPF)

Controlled Atmospheric Magnet Processing (CAMPS)

CAPABILITIES

Mining & Concentration → Extraction → Separation → Conversion to Metals → Refining & Alloying → Recycling → Fabrication → Part Manufacturing → Sub-Assembly Manufacturing → System Integration

Bench-scale metal reduction
Electrophoretic deposition

Thermal processing in high magnetic fields
Robotic magnetic property assessment
Table-top 3D magnet printing

Crosscutting Enabling Facilities & Capabilities

- Bulk and thin-film combinatoric library production facilities
- Rapid thermodynamic property assessment
- Micro-x-ray fluorescence analysis
- High precision adiabatic calorimeter
- Automated machine learning-assisted X-ray imaging defect detection
- Computational prediction and automated synthesis of molecules/ligands using AI/machine learning-augmented robotic systems to rapidly screen and identity new ligands
- Criticality assessment tools & techniques
- Open-source software to evaluate techno-economic analysis and life-cycle assessment
- Roadmapping

CMI Hub Innovations – Magnet Supply Chain

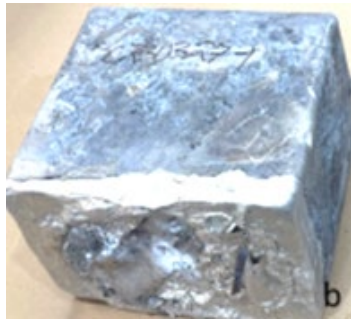
Critical Materials Innovation Hub

[Learn More: CMI Technologies with Magnets]

Mining & Concentration | Extraction | Separation | Conversion to Metals | Refining & Alloying | Recycling | Fabrication | Part Manufacturing | Sub-Assembly Manufacturing | System Integration

Efficient Flotation

Low Temperature Metallization



Critical REE-Lean Magnets

Cast Critical REE-Free Gap Magnets

Hot-roll Dy-free Nanograin Neo Magnet

Additively Manufactured Bonded Magnets

One-step HCl Leaching

Membrane Solvent Extraction

Novel Ligands for Improved Oxide Separation

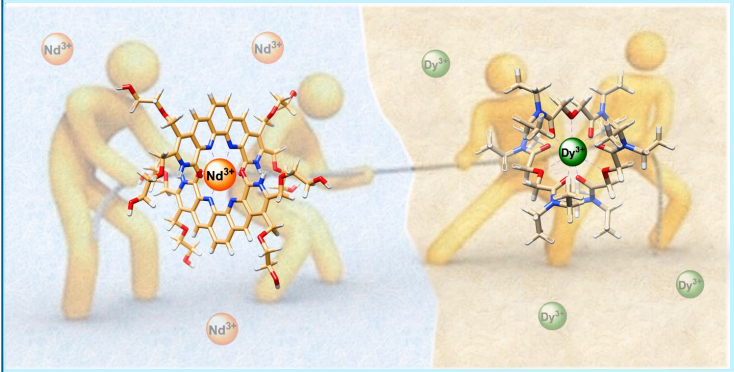
Electrochemical, Acid-free, Bio-based, & Automated Recycling Technologies

From Basic Science to Commercialization

Commercialization of highly selective processes is underpinned by basic science discovery

Basic Science

New strategies for separation of rare earth elements discovered through computation modeling and X-ray adsorption spectroscopy.



Applied R&D

Novel ligands/extractants were designed that show improved separation of rare earth elements.

These outperform the industry standard with implications to reduce cost and footprint of the separation process.

Technology Commercialization

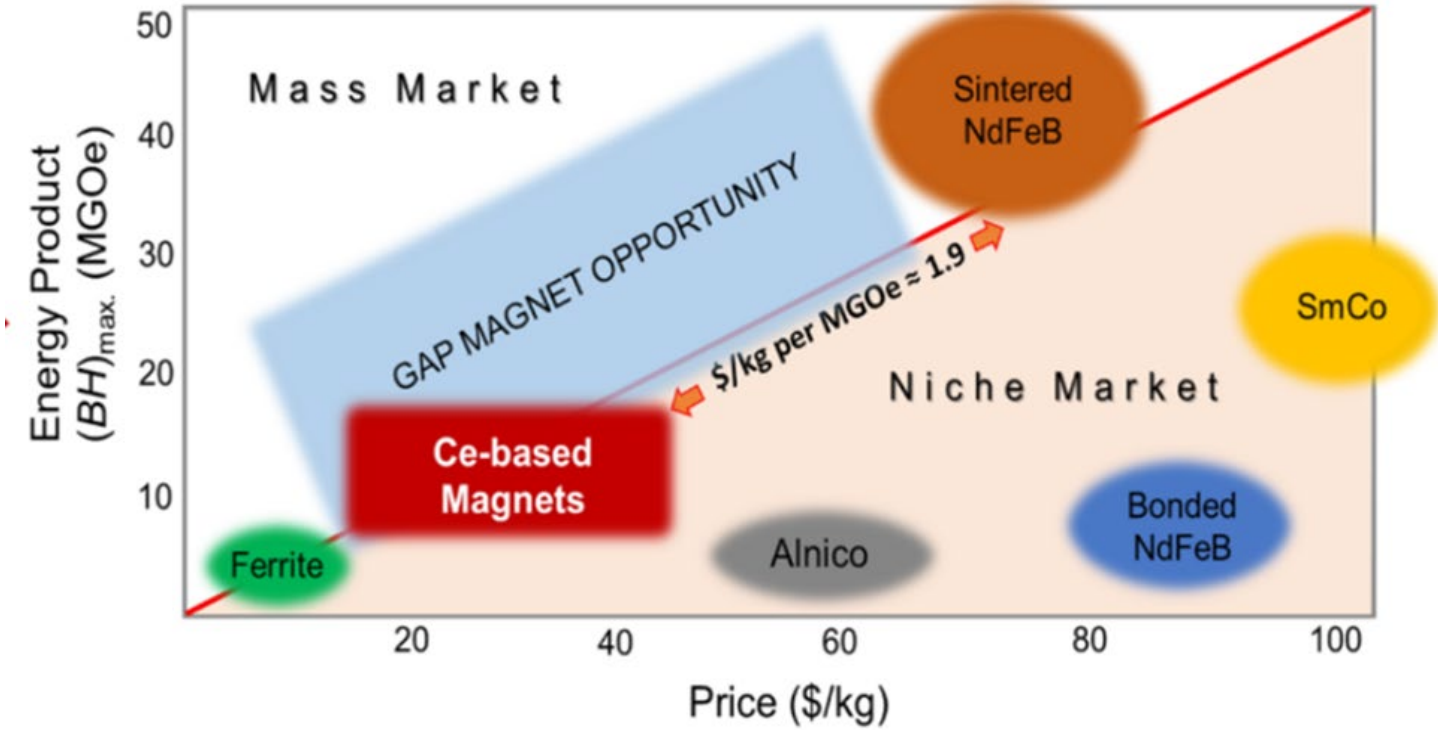
CMI industry partner Marshallton Research Laboratories licensed the technology and is working to commercialize the production of the novel ligands to meet the needs from a variety of companies.

"We're working with several companies while also improving and scaling up manufacturing processes," Foster explains.

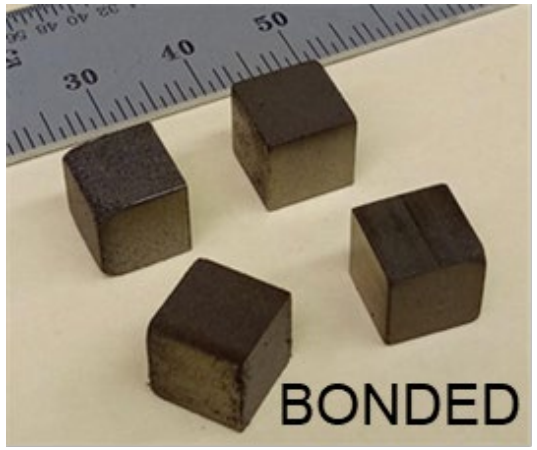
“Gap” Magnets – Addressing the REE Balance Probl

Critical Materials Innovation Hub

- One-step cast cerium-based “gap” magnet ingot
- 4 MGOe bonded magnet with 50% better remanence than bonded ferrite magnets



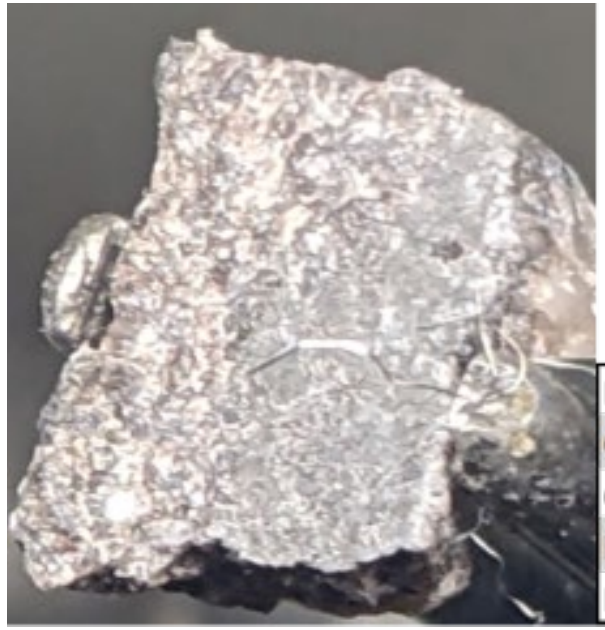
2023 R&D 100 WINNER

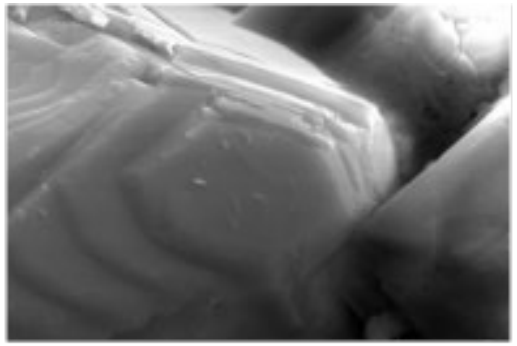


Improved Metal Reduction

- Proprietary dimensionally-stable anode enables stable, energy-efficient neodymium electrolysis from chloride melts
- Eliminates CO2 and PFC emissions

- Low temperature, semi-continuous reduction from neodymium salts





Element	Net Counts	Weight %	Atom %
O (k)	2368	0.31	2.59
Cl (k)	20464	1.43	5.4
K (K)	3865	0.27	0.94
Nd (L)	672483	97.99	91.07

Building a Circular Economy – Pilot Development

CMI Critical Materials Innovation Hub

Acid-free dissolution recycling

- Eliminates operational hazards and negative environmental impacts
- >99.5% pure NdPr and Dy oxide from e-waste (800 kg batch size)
- Modular scale-up

2018 R&D 100 WINNER

TechConnect INNOVATION AWARD 2019

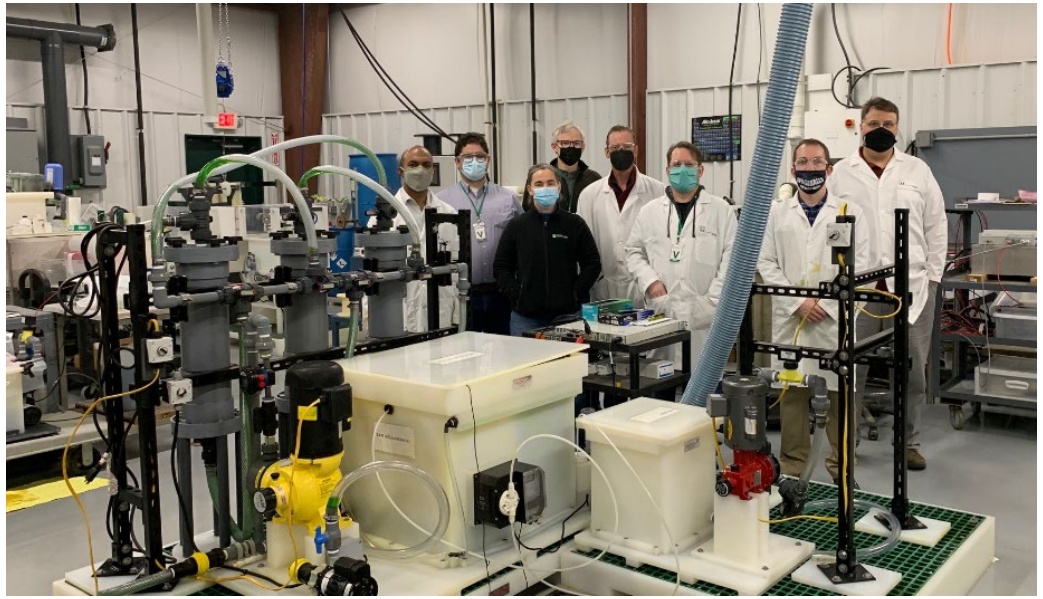
Shredded hard disk drives (HDDs) prior to recycling

Shredded HDDs after REEs leaching

Sample of recovered rare earth oxide

Electrochemical Recovery (E-RECOV)

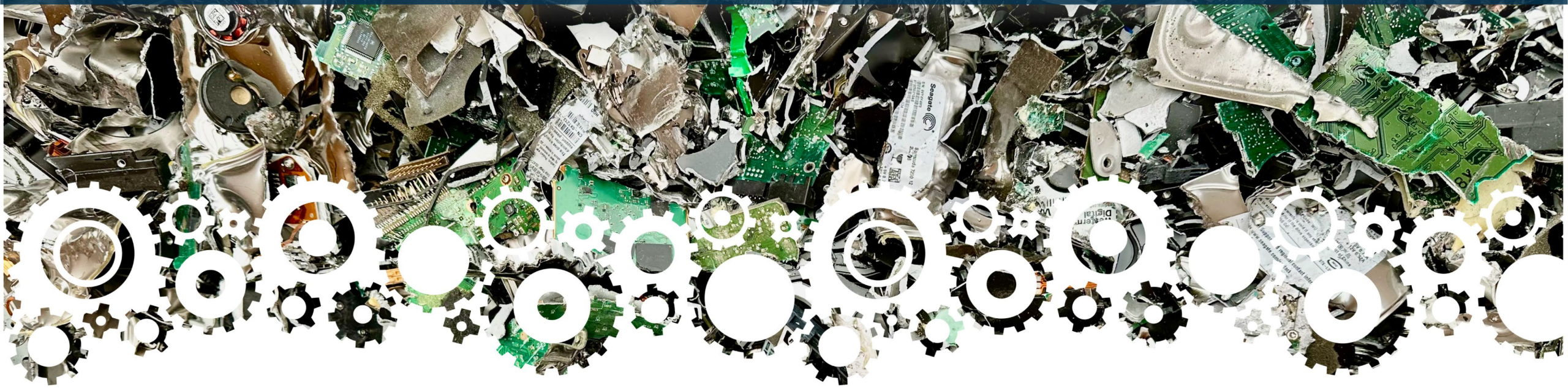
- Low temperature recovery of PGMs and REEs from e-waste
- No solvents used
- Co-recovery of gold, silver, steel



AMERICAN MADE
U.S. DEPARTMENT OF ENERGY

Electronics Scrap Recycling Advancement Prize (E-SCRAP)

Phase 1 Submission Due Sept. 4!



Phase 1

INCUBATE

- Up to 10 winners
- $50,000 cash prize per winner
- Up to $50,000 of analysis consulting

Phase 2

PROTOTYPE

- Up to 5 winners
- $150,000 cash prize per winner
- Up to $100,000 of analysis technical support

Phase 3

DEMONSTRATE

- Up to 3 winners
- $600,000 cash prize per winner

Education & Workforce Development

Critical Materials Innovation Hub

Training the next-generation of scientists and engineers to address critical material needs for the nation

Over 300 CMI Hub alumni are applying their skills in roles at government, national labs, universities, and industry

- **CMI Leadership Academy**
  - Develops leadership management skills for a group of emerging leaders within the CMI community
- **CMI Winter Meeting at Mines**
  - Annual graduate and postdoctoral professional two-day research seminar
- **CMI Internships & Externships**
  - Research collaboration at CMI team member institutions
- **Educational Outreach**
  - Exhibit at the Colorado School of Mines Geology Museum
  - K-12 educational toolkits for teachers and instructors
  - Webinars, professional societies, undergraduates, high-school students

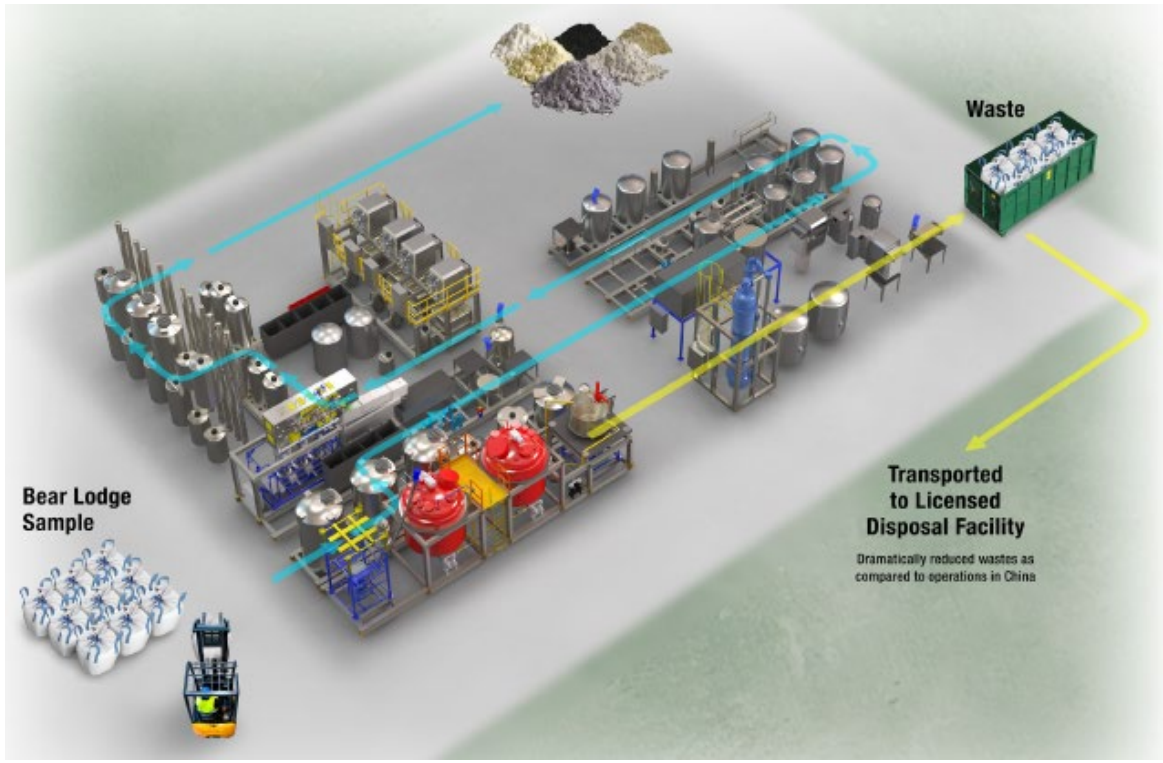
First-of-Kind Demonstration Projects

Battery-Grade Lithium Hydroxide

- American Battery Technology Company – construction is complete!

High Purity Separated Rare Earth Oxides

- General Atomics, RER, UIT – construction anticipated to be completed by Aug. 2024



Stay Connected

Learn more about DOE's Critical Materials Program
energy.gov/cmm/critical-minerals-materials-program

Connect with the CMC
energy.gov/cmm/critical-materials-collaborative
cmc@hq.doe.gov

Connect with the CMI Hub
https://www.ameslab.gov/cmi
Partner Relations: sjoiner@ameslab.gov

helena.khazdozian@ee.doe.gov